

Research Article

Effect of Inter-row Spacing of Carrot Cultivars (*Daucus carota* L.) at Wolaita Soddo, South Ethiopia

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Abstract

Systematic studies on effect of inter-row spacing on carrot cultivars are limited at Wolaita area. Therefore, this study was conducted at Wolaita Soddo University plant science and horticulture research cite in 2017 cropping season to evaluate effect of inter-row spacing on growth, yield and quality of carrot cultivars. The research was conducted in randomized complete block factorial design in 3 replications. Nantes and Haramaya I carrot cultivars were evaluated at 5 inter-row spacing of 10 cm, 20 cm, 30 cm, 40 cm and 50 cm. Phenological data, growth data, yield data, quality related data and alternaria blight severity and incidence occurred during plant growth were collected during experimental period. Most of collected data shows significant difference in between cultivars, inter-row spacing as well as their interaction. According to the result, Haramaya I show vigorous growth than nantes. However, in total yield and marketable yield and quality parameters nantes is found better than Haramaya I. As far as inter row is concerned, even if narrow inter-row spacing shows longer in plant height and leaf length, wider inter-row spacing shows vigorous plant growth and lower disease incidence and severity. However, in yield and quality parameter best result was obtained in narrowest inter-row spacing. Generally, best result of 37.95 tons of total yield per hectare was obtained at nantes variety grown in 10 cm by 10 cm spacing. Similarly, better marketable yield was obtained in this variety and spacing. Notably, the highest marketable root yields of 8.7 t ha⁻¹ for the Nantes variety and 15.2 t ha⁻¹ for another option were achieved with 10 cm inter-row spacing. Consequently, the Nantes cultivar paired with a 10 cm x 10 cm spacing emerges as a promising combination for growers. However, since this research was conducted over just one season and limited to a single location, it is advisable to further explore this study across different locations and seasons for more comprehensive recommendations.

Keywords

Growth, Quality, Yield and Marketable

1. Introduction

Carrot (*Daucus carota* L.) is a biennial herbaceous plant that belongs to the genus *Daucus*, species *carota*, and is a member of the Apiaceae family [16]. It is cultivated in temperate climates

during spring, summer, and autumn, while in tropical and sub-tropical climates; it is grown in winter [3]. It contains high amount

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Received: 5 January 2026; Accepted: 30 January 2026; Published: 24 February 2026



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of carotenoids which have several health benefit. In addition, carrot has several macro and micro nutrients having nutritional and health importance [27]. It also increase resistance capacity of different communicable human diseases and prevent against several non-communicable human diseases like blood pressure, cancer, heart diseases and other [4].

In Ethiopia, there exists an endemic relative of *Daucus carota* that naturally occurs in mountainous regions. *Daucus hochstetteri* is frequently found in grasslands on rocky hills, in valleys, and in open, often eroded areas within upland and evergreen bushland, at elevations ranging from 1650 to 2700 meters above sea level. Promoting carrot cultivation and domestic consumption in Ethiopia serves as a strategy to enhance nutritional standards and mitigate the prevalence of night blindness in mothers and children, which is caused by vitamin A deficiency [5]. Smallholder farmers have produced a total yield of 16,751.38 tons, contributing approximately 0.42% to the nation's overall root and tuber crop production [6]. The area dedicated to carrot cultivation is gradually increasing, primarily due to its ease of production and the expansion of small-scale rain-fed and irrigated areas [30]. Average productivity of carrot in Ethiopia is lower than world average productivity [6, 7]. This will be due to inappropriate cultural practice, like wrong planting time, scarcity of improved varieties, wrong space between plants and rows, poor disease and insect pest management [30]. The levels of fertilization, soil tillage, and other factors may interact in various ways, depending on the cultivar used [2].

To further enhance the quality of organic products and ensure yield stability, it is essential to develop new cultivars that are well-suited to organic farming systems. The potential for achieving high yields is significantly dependent on the careful consideration of the optimal number of plants per unit area and the arrangement pattern of the specified quantity of seeds or plant population in the planting field [9]. This is because the amount of solar radiation that penetrates a crop canopy is greatly influenced by planting patterns or spacing, as well as the morphology of individual plants [12].

The fragmented research conducted on carrots thus far has been dispersed across various institutions in Ethiopia and has not been compiled into a comprehensive document [13]. Nevertheless, no studies have been undertaken to assess the impact of inter-row spacing on the yield of carrot cultivars under Wolaita conditions [25]. Although the choice of cultivar and inter-row spacing may vary based on agro-climatic conditions, no more study was carried out to identify the optimal cultivar and suitable inter-row spacing for maximizing root yields. Therefore, the aim of this research was to evaluate the impact of inter-row spacing on growth, root yield, and quality of carrot cultivars.

2. Materials and Methods

2.1. Description of the Study Area

The experiment was carried out under rain-fed conditions

at the experimental site of the Department of Horticulture, Wolaita Sodo University, Ethiopia, during the cropping years of 2017. The experimental site is situated at 60 49'N, 370 45'E, with an elevation ranging from 1600 to 2400 m.a.s.l. This area receive average annual rain fall of 1580 mm, with average annual highest temperatures of 23.7°C and the lowest average annual temperature of 17.7°C the relative humidity between 56.0% and 75.2% [21]. The primary soil types study area are reported to be Nitosols [10] and sandy loam [15].

2.2. Treatments and Experimental Designs

The experiment was carried out utilizing a factorial combination of two carrot cultivars (Nantes and Haramaya I) and five different row spacings (10 cm x 10 cm, 20 cm x 10 cm, 30 cm x 10 cm, 40 cm x 10 cm, and 50 cm x 10 cm) as treatments. It was organized in a randomized complete block design (RCBD) with three replications. The size of each plot in the experiment was 3 m² (2 m × 1.5 m), consisting of 20, 10, 6, 5, and 4 rows with inter-row spacings of 10 cm, 20 cm, 30 cm, 40 cm, and 50 cm, respectively, while the net plot size was 1 m x 1 m (1 m²). The space between blocks were 1 m and the space between the plots were 0.5 m.

2.3. Field Management and Cultural Practice

The experimental field was meticulously ploughed using locally sourced materials to a depth of 30 cm to achieve a fine tilth. The field was then leveled and segmented into plots according to the experimental layout. Seeds were sown at a depth of 1.5 cm in rows corresponding to the treatment, with a seed rate of 5 kg ha⁻¹. Urea and NPS were applied at rates of 89 and 121 kg ha⁻¹, respectively. This application rate was derived from the recommended rates of DAP at 100 kg ha⁻¹ and Urea at 100 kg per hectare respectively [31]. All the NPS was applied at sowing date and half of urea was applied at sowing date and the remaining was applied after second thinning. Thinning was performed twice to ensure an optimal plant population, maintaining a distance of 10 cm between plants as per the treatments. Two thinning was done at 20 days and 30 days after sowing respectively. Similarly, two Earthing up was done at 30 days and 60 days after sowing [22]. All plant management practices were uniformly implemented across all treatments.

2.4. Data Collected

Root yield was obtained from the entire net plot, while for the other parameters, 10 plants from the central rows were randomly chosen and tagged. The collected data included: days to emergence, days to maturity, plant height (cm), number of leaves per plant, leaf length (cm), above-ground weight (g), fresh root to shoot ratio (%), dry weight of the aerial part (g plant⁻¹), root weight per plant (g), root length (cm), root diameter (cm), dry weight of root (g plant⁻¹), root yield (t ha⁻¹), marketable root yield (t ha⁻¹), core diameter (cm), core length

(cm), core weight (g), shelf life (days) at room temperature, total soluble solids, and root water content (%).

During the maturity stage of the plant, foliar disease occurred. The disease was identified through macroscopic (visual observation) and microscopic (using a microscope) examinations as *Alternaria* blight. Disease incidence and severity were recorded, with disease incidence (%) calculated by counting the total number of plants exhibiting visible symptoms, dividing by the total number of plants assessed, and multiplying by 100. Disease severity (%) was measured by evaluating the area of plants with visible symptoms, dividing by the total area of plants assessed, and multiplying by 100.

2.5. Analysis of Data

To analyze the collected data SAS statistical software was used [26]. To distinguish significant differences between and among treatment means, Fisher's Least Significant Difference (LSD) test was applied at a significance level of $P < 0.05$.

3. Results and Discussion

This study demonstrated that the time taken to reach 50% emergence of the carrot was significantly ($P < 0.01$) influenced by the primary effect of cultivar, as well as the combined effects of cultivar and inter-row spacing on the time to 50% maturity (see Table 1). In this regard, cultivar Haramaya I emerged more quickly (7.53 days) compared to cultivar Nantes (9.13 days). Additionally, Table 1 revealed that there was no significant ($P < 0.05$) difference in days to emergence when varying inter-row spacing was applied. Cultivar Haramaya I was identified as the early maturing variety, taking 93.47 days. The data analysis concerning maturity by cultivar indicated that the longest duration (95.07 days) was recorded for the Nantes cultivar. Furthermore, the results presented in Table 1 suggested that the days to maturity were contingent upon the primary effects of cultivar and row spacing. Among the inter-row spacings tested, the earliest maturity (90.00 days) was noted for the 10 cm X 10 cm spacing, while the latest maturity (96.83 days) was observed for the 50 cm X 10 cm spacing.

Table 1. Main effects of cultivar and inter row spacing on phenological parameters.

Treatment	Days to emergence	Days to maturity
Cultivar		
Nantes	9.13a	95.07a
Haramaya I	7.53b	93.47b
LSD (0.05)	0.46	1.34
inter row spacing (cm)		
10	8.17	90.00c
20	8.50	94.67b
30	8.33	94.33b
40	8.33	95.50ab
50	8.33	96.83a
LSD (0.05)	Ns	2.12
CV (%)	7.27	1.86

Average values having similar letters with in column indicates non significance difference at $P = 0.05$ level of significant. ns = non-significant.

Except plant height and leaf length per plant, the data concerning leaf count per plant, inter-row spacing, plant height, dry weight of the aerial part per plant, and the fresh root to shoot ratio exhibited significant differences ($P < 0.01$) in the main effects of cultivar and inter-row spacing (Table 2). Significant differences at $P < 0.01$ were observed between the two cultivars. The cultivar Haramaya I recorded a significantly taller plant height of 57.93 cm, while the cultivar Nantes had a shorter plant height of 33.53 cm. The cultivar Haramaya I also recorded a higher mean number of leaves (12.54) compared to Nantes, which had a lower mean

of 9.94 (Table 3). Additionally, the mean leaf length for Haramaya I was longer at 53.12 cm, whereas Nantes had a shorter mean leaf length of 30.24 cm. The mean dry weight of the aerial part per plant was higher for Haramaya I at 5.60 g compared to Nantes, which had a dry weight of 4.43 g. In terms of spacing, the highest dry weight of the aerial part per plant (7.06 g) was achieved with a spacing of 50 cm x 10 cm, followed by a dry weight of 5.69 g with a spacing of 40 cm x 10 cm. The lowest dry weight of the aerial part per plant (3.20 g) was recorded with a spacing of 20 cm x 10 cm. Regarding the main effect of cultivar

on the root to shoot ratio, the maximum value (1.94%) was recorded for Nantes. Conversely, the lowest fresh root to shoot ratio (0.63%) was observed for cultivar Haramaya I. In terms of row spacing, the highest fresh root to shoot ratio (1.76%) was

achieved with a spacing of 10 cm x 10 cm, while the lowest fresh root to shoot ratio (0.98%) was recorded with a spacing of 50 cm x 10 cm (Table 2).

Table 2. Main effect of spacing and cultivar on aerial growth parameters.

Treatment	PH (cm)	LNPP	LLPP (cm)	DWAPP (g)	FRSR (%)
Cultivar					
Nantes	33.53b	9.94b	30.24b	4.43b	1.94a
Haramaya I	57.93a	12.54a	53.12a	5.60a	0.63b
LSD (0.05)	6.37	1.57	6.10	0.90	0.28
Inter row spacing (cm)					
10	54.15	9.42c	49.85	4.41bc	1.76a
20	46.87	9.53c	42.28	3.20c	1.30b
30	46.52	10.43bc	41.83	4.71b	1.21b
40	41.27	12.25ab	37.93	5.69ab	1.17b
50	39.85	14.56a	36.50	7.06a	0.98b
LSD (0.05)	Ns	2.48	Ns	1.42	0.44
CV (%)	18.15	18.20	19.09	23.27	28.12

Average values having similar letters with in column indicates non significance difference at P= 0.05 level of significant. ns = non-significant; DWAPP = dry weight of aerial part per plant (g); FRSR = fresh root to shoot ratio (%); LLPP = leaf length per plant (cm); LNPP = number of leaf in each plant and PH = height of plant (cm).

The interaction effect of various cultivars and inter-row spacing on the average fresh weight of aerial parts per plant was determined to be significant ($P < 0.01$) during the study (Table 3). The combined effect of Haramaya I and a spacing of 50 cm x 10 cm resulted in a significantly higher fresh weight of aerial parts per plant, measuring 129.53 g, compared to the other treatment combinations. This was followed by Haramaya I with a spacing of 40 cm x 10 cm, which recorded

92.45 g. Cultivar Haramaya I with a spacing of 30 cm x 10 cm, Haramaya I with a spacing of 20 cm x 10 cm, and Nantes with a spacing of 50 cm x 10 cm recorded fresh weights of 90.28 g, 47.80 g, and 33.56 g of aerial parts per plant, respectively. The lowest fresh weight of aerial parts per plant, measuring 12.13 g, was observed in the Nantes cultivar with a spacing of 20 cm x 10 cm.

Table 3. Interaction effect of cultivar and inter row spacing on fresh weigh of aerial parts per plant.

Inter row spacing (cm)	Cultivar	
	Haramaya I	Nantes
10 cm	28.02cde	14.23de
20 cm	47.80c	12.13e
30 cm	90.28b	20.97de
40 cm	92.45b	23.55de
50 cm	129.53a	33.56cd
LSD (0.05)	21.07	

Inter row spacing (cm)	Cultivar	
	Haramaya I	Nantes
CV (%) 24.94		

Average values having similar letters with in column indicates non significance difference at P= 0.05 level of significant.

The data regarding the fresh weight of roots, dry weight of roots, and total root yield indicated significant differences ($P < 0.05$) between the two cultivars and across various inter-row spacings (Table 4), as well as an interaction effect between cultivar and spacing. The combination of Haramaya I with a spacing of 50 cm $\times$ 10 cm exhibited a significantly higher root fresh weight of 61.38 g, followed closely by Haramaya I with a spacing of 40 cm $\times$ 10 cm, which recorded 61.20 g, in comparison to the other treatment combinations. Conversely, the lowest fresh weight of roots, measuring 23.73 g, was observed in the Nantes cultivar with a spacing of 20 cm $\times$ 10 cm. Furthermore, the combination of Haramaya I and a spacing of 50 cm $\times$ 10 cm also yielded the highest root dry weight at 21.32 g, surpassing all

other treatment combinations; this was followed by Haramaya I with a spacing of 40 cm $\times$ 10 cm, which recorded a root dry weight of 16.88 g. The significantly lowest dry weight of roots, at 3.23 g, was noted in the Nantes variety with a spacing of 20 cm $\times$ 10 cm. Notably, the highest yield of 37.95 t ha⁻¹ was achieved with the treatment combination of the Nantes cultivar and a spacing of 10 cm $\times$ 10 cm, compared to other treatment combinations, followed by the Haramaya I cultivar with a spacing of 10 cm $\times$ 10 cm, which yielded 32.1 t ha⁻¹ (Table 4). The lowest root yield per hectare, recorded at 7.95 t ha⁻¹, was obtained from the Nantes cultivar combined with a spacing of 50 cm $\times$ 10 cm.

Table 4. Interaction effect of spacing and cultivar on yield parameters.

Cultivar	Row spacing (cm)	RFWPP (g)	RDWPP (g)	Total yield (t ha ⁻¹)
Haramaya I	10	32.10de	6.52cd	32.10a
	20	29.78de	6.08cd	14.89bc
	30	57.37ab	15.94b	20.46b
	40	61.20a	16.88b	14.81bcd
	50	61.38a	21.32a	11.47cd
Nantes	10	37.95cd	3.98ef	37.95a
	20	23.73e	3.23f	11.87cd
	30	34.45d	5.52cde	11.34cd
	40	47.58bc	4.81def	12.62cd
	50	56.68ab	6.99c	7.95d
LSD (0.05)		10.65	1.83	6.90
CV (%)		14.03	15.98	22.93

Average values having similar letters with in column indicates non significance difference at P= 0.05 level of significant. ns = non-significant. RDWPP = root dry weight per plant (g) and RFWPP = root fresh weight per plant (g).

Except for root length per plant in row spacing, the data regarding marketable root yield per hectare, root length, and root diameter per plant exhibited differ significantly ($P < 0.05$) among the two cultivars as well as between inter-row spacing's. Concerning cultivars, the highest marketable yield (8.70 t ha⁻¹) was achieved by the Nantes cultivar. In contrast, the lowest marketable root yield per hectare (7.33 t ha⁻¹) was

noted for Haramaya I (Table 5). Regarding row spacing, the maximum marketable yield (15.26 t ha⁻¹) was recorded at 10 cm $\times$ 10 cm, followed by 20 cm $\times$ 10 cm (6.88 t ha⁻¹), while the minimum (5.12 t ha⁻¹) marketable yield was observed at 50 cm $\times$ 10 cm spacing. The Haramaya I cultivar demonstrated the longest root length per plant (15.32 cm), whereas the Nantes cultivar exhibited the shortest root length per plant

(13.09 cm) (Table 5). Although no significant difference was found between the spacings, the longest root diameter (16.02 cm) was achieved with a spacing of 50 cm x 10 cm, and the shortest root length (12.74 cm) was recorded at 10 cm x 10 cm spacing. Among the various plant spacings utilized in this study, the 50 cm x 10 cm spacing recorded the highest root diameter significantly (2.76 cm), while the lowest root diameter (1.80 cm) was noted in the 20 cm by 10 cm space. In terms

of cultivars, the highest root diameter (2.47 cm) was recorded for Haramaya I, while the lowest root diameter (2.20 cm) was obtained from the Nantes cultivar. Root diameter diminished as plant density increased, likely due to competition for light, moisture, and nutrients; conversely, wider spacing allows for greater root development, resulting in a maximum root diameter (Table 5).

Table 5. Effects of cultivars and row space on root length, root diameter and marketable yield.

Treatment	RLPP (cm)	RDPP (cm)	MY (t ha ⁻¹)
Cultivar			
Nantes	13.10b	2.20a	8.70a
Haramaya I	15.32a	2.47a	7.33b
LSD (0.05)	1.72	0.29	1.22
Row spacing (cm)			
10	12.74	2.20bc	15.26a
20	12.90	1.80c	6.88b
30	14.47	2.61ab	6.77b
40	14.92	2.30ab	6.06b
50	16.02	2.76a	5.12b
LSD (0.05)	Ns	0.46	1.92
CV (%)	15.80	16.34	19.76

Average values having similar letters with in column indicates non significance difference at P= 0.05 level of significant. ns = non-significant. ns = non significant; RDPP = root diameter per plant (cm); RLPP = root length per plant (cm) and MY = marketable yield (t ha⁻¹).

Interaction effect between cultivars and inter-row space was found to be significantly different at $P < 0.05$ concerning both disease incidence and severity. The highest recorded disease incidence (100%) occurred in the treatment combination of cultivar Haramaya I with a spacing of 10 cm x 10 cm, as well as cultivar Nantes with the same spacing of 10 cm x 10 cm. The second highest disease incidence (96.67%) was noted in the treatment combination involving cultivar Haramaya I with a spacing of 30 cm x 10 cm. Conversely, the lowest disease incidence (33.33%) was observed in the treatment combination of Nantes cultivar with a spacing of 40 cm x 10 cm. The highest disease se-

verity (27%) was documented in the treatment combination of cultivar Nantes with a spacing of 10 cm x 10 cm, followed closely by the treatment combination of cultivar Haramaya I with 10 cm x 10 cm spacing, which exhibited a disease severity of 25%. The lowest disease severity (0.67%) was recorded in the combination of Haramaya I cultivar with a spacing of 50 cm x 10 cm. Although higher disease severity was noted in narrower spacing compared to other spacings, it did not significantly affect root yield or marketability. This may be attributed to the fact that the disease manifests at the maturity stage, which occurs after the formation of mature roots (Table 6).

Table 6. Combined influence of cultivars and row space on disease incidence as well as disease severity.

Cultivar	Row spacing (cm)	DI (%)	DS (%)
Haramaya I	10	100.00a	25.00a
	20	83.33ab	5.00cd
	30	96.67a	10.00b

Cultivar	Row spacing (cm)	DI (%)	DS (%)
Nantes	40	83.33ab	4.00cde
	50	43.33cd	0.67e
	10	100.00a	27.00a
	20	70.00abc	7.33bc
	30	60.00bcd	2.27de
	40	33.33d	2.00de
	50	70.00abc	2.67de
LSD (0.05)		33.76	3.89
CV (%)		26.60	26.42

Average values having similar letters with in column indicates non significance difference at P= 0.05 level of significant. DI = disease incidence (%) and DS=disease severity (%).

The analysis of core weight per plant and core length per plant revealed significantly varies ($P < 0.05$) among the cultivars, across different row spacings, and due to the interaction between cultivar and inter-row spacing (Table 7). The treatment combination of cultivar Haramaya I with a spacing of 50 cm x 10 cm yielded the highest core weight per plant at 29.89 g, followed by cultivar Haramaya I with a spacing of 40 cm x 10 cm, which produced a yield of 23.27 g. Conversely, the lowest core weight per plant, recorded at 5.51 g, was associated with the

Nantes cultivar at a spacing of 20 cm x 10 cm. In terms of core length per plant, the highest measurement of 16.27 cm was observed in the treatment combination of cultivar Haramaya I with a spacing of 40 cm x 10 cm, followed closely by cultivar Haramaya I with a spacing of 30 cm x 10 cm, which achieved a core length of 16.07 cm. The lowest core length per plant, measuring 10.23 cm, was noted for the Nantes cultivar with a spacing of 30 cm x 10 cm (Table 7).

Table 7. Interaction effect of cultivar and spacing on quality parameter.

Cultivar	Row spacing (cm)	CWPP (g)	CLPP (cm)
Haramaya I	10	6.84de	12.13bcd
	20	5.97de	11.00cd
	30	18.89c	16.07a
	40	23.27b	16.27a
	50	29.89a	14.00abc
Nantes	10	6.67de	10.83cd
	20	5.51e	12.80abcd
	30	5.71e	10.23d
	40	8.73d	13.13abcd
	50	16.03c	15.73ab
LSD (0.05)		2.98	3.62
CV (%)		13.60	15.98

Average values having similar letters with in column indicates non significance difference at P= 0.05 level of significant. CWPP = cores weight in each plant (g) and CLPP= core length per plant (cm).

The information displayed in Table 8 indicated that the cultivars exhibited significant differences ($P < 0.01$) regarding their core diameter per plant, water content, and total soluble solute. Nevertheless, no significant variations ($P < 0.05$) were noted in shelf life as a result of cultivar influence. Apart from core diameter per plant, water content, total soluble solute, and shelf life were not significantly affected ($P < 0.05$) as a primary effect of row spacing. The greatest root core thickness (1.41 cm) was recorded for the cultivar Haramaya I, surpassing Nantes (0.95 cm). Additionally, Haramaya I demonstrated a higher total soluble solids (TSS) content of 13.05°Brix compared to the

Nantes cultivar, which had 9.30°Brix. The highest water content (85.34%) was achieved by the Nantes cultivar, in contrast to Haramaya I cultivar (72.84%). This variability may stem from genetic differences among cultivars concerning their water content. A significantly larger core diameter (1.26 cm) was observed at the spacing of 40 cm x 10 cm when compared to other treatments. Conversely, the smallest core diameter per plant (0.12 cm) was recorded at the 10 cm x 10 cm spacing. The increase in root diameter with greater spacing may have contributed to the elevated core diameter values at the 50 cm x 10 cm spacing (Table 7).

Table 8. Main effect of spacing and cultivar on quality parameter.

Treatment	CDPP (cm)	WC (%)	TSS (°Brix)	SL (days)
Cultivar				
Nantes	0.95b	85.34a	9.30b	20.73
Haramaya I	1.41a	72.84b	13.05a	20.67
LSD (0.05)	1.41a	4.67	1.402	ns
Row spacing (cm)				
10	0.12c	82.38	10.19	20.33
20	1.02cb	82.38	10.52	21.00
30	0.92c	79.31	11.11	20.00
40	1.26ab	78.80	11.26	21.33
50	1.25ab	73.71	12.79	20.83
LSD (0.05)	20.11	Ns	Ns	Ns
CV (%)	0.24	7.70	16.34	8.11

Average values having similar letters with in column indicates non significance difference at $P = 0.05$ level of significant. CDPP = diameters of core in each plants in cm; ns = non significant; SL = shelf life (days); TSS = total soluble solute (%) and WC = water content (%).

The prevailing weather conditions and the specific cultivar cultivated in a given area collectively influenced the growth and yield characteristics of the cultivars. Variations in growth parameters associated with different cultivars have also been documented by [22]. He noted that the improved Kuroda variety exhibited a significantly greater maximum plant height of 44.28 cm. Likewise, [1] reported a significantly higher plant height for the treatment with closer spacing. Variations in growth parameters related to cultivars have also been noted by [20]. According to [31], Nantes exhibited a greater leaf length per plant compared to Haramaya I. This discrepancy may arise from the fact that different genotypes express themselves differently across various growing environments. The differences observed in varietal responses could be attributed to the genetic makeup influencing the expression of growth potentials.

In terms of the effect of spacing on the numbers of leave in each plant, there was a noticeable increase in the number of

leaves per plant, rising from 9.42 at a spacing of 10 cm x 10 cm to 14.56 at a spacing of 50 cm x 10 cm. The findings of the current study align with those of [18], who discovered that plants spaced at wider intervals (40 cm x 10 cm) produced a greater number of leaves and higher foliage dry matter. Similar findings were reported by Muhammad, A. A. et al., who demonstrated that widely spaced plants had a higher number of leaves per plant compared to those planted closely together in carrots [19]. This phenomenon may be attributed to the wider spacing, which lessened competition for soil nutrients, moisture, carbon dioxide, and light among the plants. This likely enhanced photosynthesis, leading to the production of more leaves and broader canopies. [7] also identified significant differences resulting from varying spacing. Furthermore, [20] indicated that plots with wider spacing exhibited significantly higher dry weight values, likely due to reduced competition among plants in those plots.

The data revealed that an increase in spacing leads to a decrease in the fresh root to shoot ratio. This suggests that wider spacing encourages greater aerial vegetative growth compared to root growth. Conversely, narrow spacing promotes enhanced root development. This phenomenon may be attributed to the fact that wider spacing allows for more aerial vegetative growth than narrow spacing. These findings are consistent with the results reported in [22], which indicated significant differences among cultivars regarding their root to shoot ratios. In both cultivars, an increase in spacing also resulted in a rise in the fresh weight of aerial parts per plant. This outcome may be explained by the reduced competition for light, moisture, and nutrients in wider spacing, leading to optimal growth. The current findings align with those of [17, 28], who noted that fresh aerial weight increases gradually with increased spacing. Likewise, [1] found that plots with wider spacing (40 cm x 10 cm) exhibited significantly greater fresh weight.

The plants cultivated under a spacing of 50 cm x 10 cm (Haramaya I) benefited from ample space for root development and experienced less nutrient competition. This, combined with the effective utilization of accumulated resources conserved by the plant, resulted in a higher fresh weight of roots. Similar findings were reported by [17], who indicated that root fresh weight also increased with wider spacing. In contrast, plants grown under the spacing of 20 cm x 10 cm (Haramaya I) and 20 cm x 10 cm (Nantes) exhibited relatively lower fresh weight due to nutrient competition among them. These results corroborate the findings of [23]. Generally, in both varieties, an increase in spacing correlates with an increase in root dry weight per plant. It was observed that wider spacing resulted in greater consumption of root dry matter compared to closely spaced carrots. A similar increase in root dry weight with increased spacing was reported by [17]. Additionally, [7] noted that over all yield and marketable yield were higher significantly in closely spaced plants than wider spaces due to the presence of more roots.

Although Haramaya I demonstrates superior results in most parameters, it has produced several branched roots that are deemed unmarketable. Carrot varieties exhibit varying responses to increased plant populations. Certain varieties are unable to withstand the heightened competition associated with larger populations, resulting in the production of numerous short, misshapen, or forked roots. Conversely, some varieties can yield high-quality roots even at populations exceeding the standard [29]. This finding contradicts the results reported in [31], which indicated that Haramaya I yields a higher marketable root output compared to Nantes. This discrepancy may stem from environmental differences, as their experiments were conducted in Eastern Ethiopia, where genotypes may express differently under varying conditions. [7] noted that plants spaced widely apart produced longer roots than those planted closely together. *Alternaria* leaf blight, caused by *Alternaria dauci*, is recognized as the primary foliar disease affecting carrots globally [8]. Differences in susceptibility among carrot cultivars have been documented by [11]. [14]

assessed various cultivars, finding a range of disease severity between 47.2% and 57.4%. Nevertheless, efforts to screen carrot cultivars for their reactions to *Alternaria* and *Cercospora* leaf blights, as well as to identify sources of resistance alleles, have been undertaken in various carrot-growing regions [24]. Similarly, [22] indicated that the cultivars significantly differed in terms of their root core thickness.

4. Conclusion

In general, the cultivar Haramaya I demonstrated significantly superior growth performance; however, both plant height and leaf length exhibited a decreasing trend as plant spacing increased. Conversely, the number of leaves increased with greater spacing. Yield results indicated that the highest root yield was achieved with the Nantes cultivar at a spacing of 10 cm x 10 cm. Additionally, the Nantes cultivar outperformed Haramaya I in terms of marketable yield. The 10 cm x 10 cm spacing was also optimal for marketable yield. Although this study was conducted at a single location over one season, it showed that varying spacing as well as cultivars had a significant impact on the plant growth and productivity. Cultivating the Nantes cultivar with a spacing of 10 cm x 10 cm has the potential to enhance carrot productivity in the experimental area and in regions with similar weather characteristics. Nevertheless, additional investigation is required in other locations and seasons to validate these findings.

Abbreviations

CSA	Central Statistical Authority
LSD	Least Significant Difference
m.a.s.l	Metter Above Sea Level
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
TSS	Total Soluble Solids
WC	Water Content

Acknowledgments

The Authors went to acknowledge Wolaita Sodo University for giving experimental site.

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Funding

The research was funded by the researchers.

Conflicts of Interest

The authors declare no conflicts of interest.

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